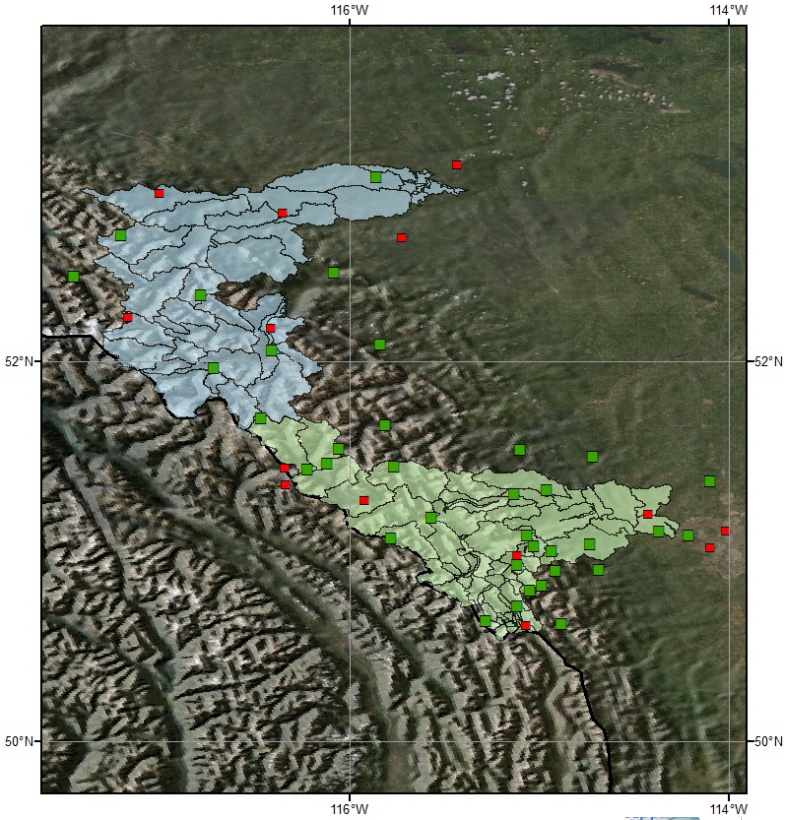
Stochastic Weather Generation for Hydrologic Analysis for Critical Design Infrastructure

Doug Hultstrand, PhD, Senior Hydrometeorologist, AWA
Bill Kappel, President/Chief Meteorologist, AWA
Peter Campbell, Project Engineer, TransAlta

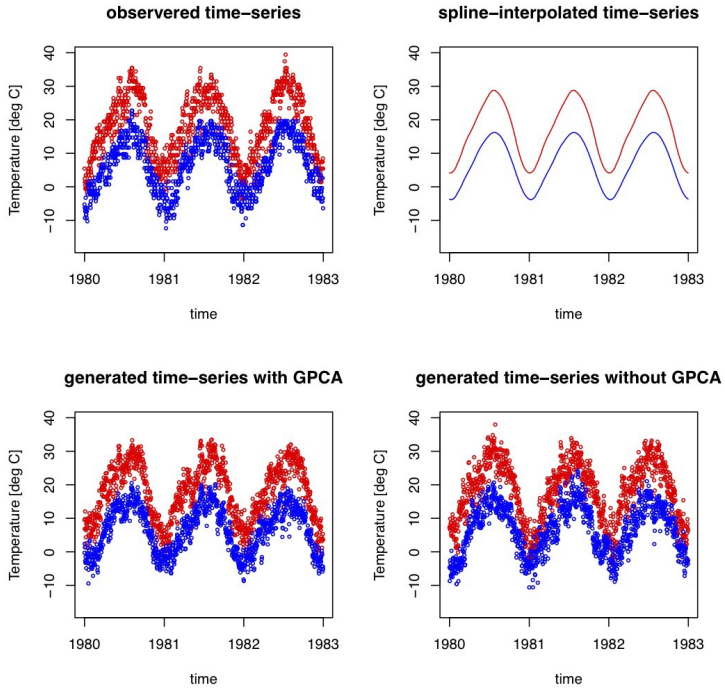
Basin Characteristics and Setting

- The Bow basin (green) is 7,292 km^2 and the North Saskatchewan basin (blue) is 9,868 km^2
- Focus on stochastic or Monte-Carlo modelling, where flood events can be simulated using either event-based or continuous hydrologic modelling
- To model the spatial rainfall correlations as input for hydrologic modeling and flood frequency development
- Based on data availability, data quality, period of record, and spatial distribution requirements



Stochastic Weather Generator

- A weather generator (WG) produces meteorological time series with the same statistical patterns of the observed
- Attempt to reproduce the spatial and temporal dynamics and correlation structures of the variables of interest
- Simulate realistic or plausible random sequences of atmospheric variables such as temperature, rainfall, wind speed, snow
- Synthetic sequences provide a set of alternate realizations that can be used for risk and reliability assessment

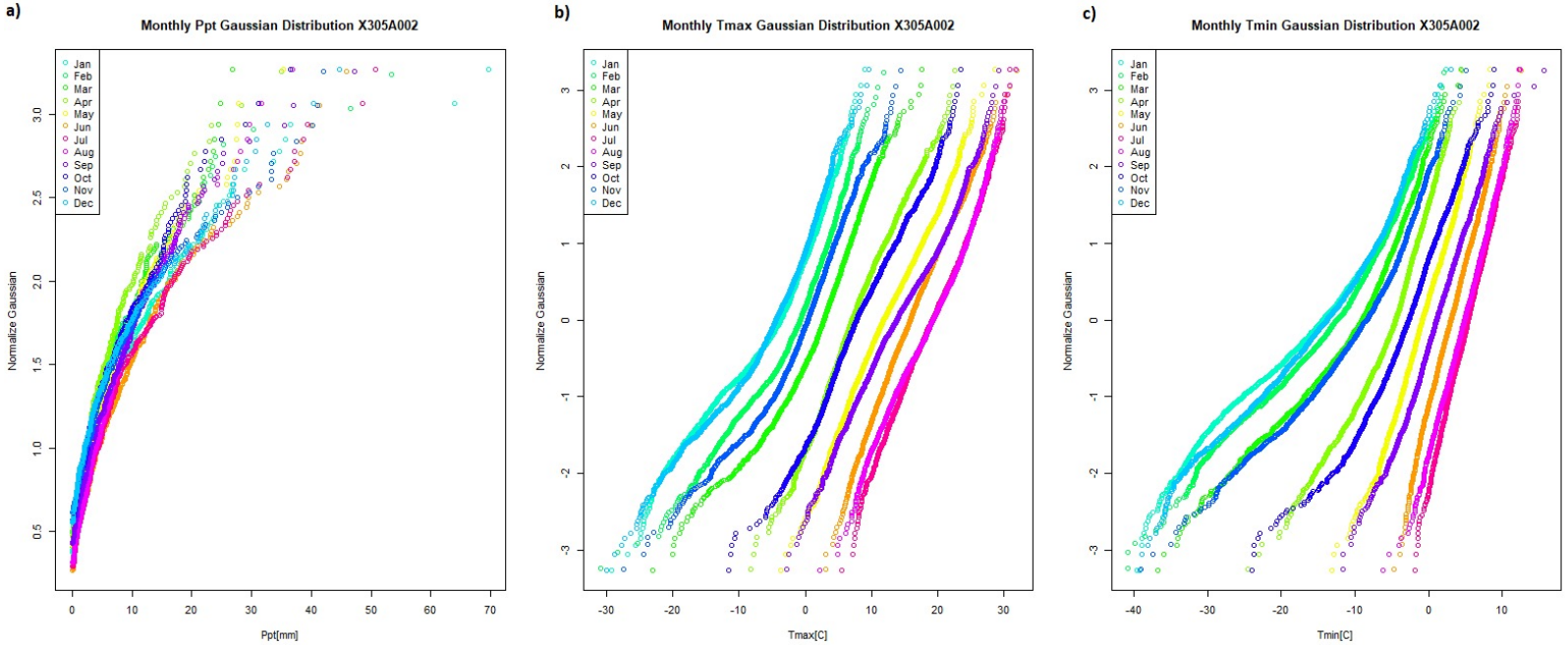


Stochastic Weather Model-RMAWGEN

- RMAWGEN selected because it can maintain temporal and spatial correlations among the station data
- Observed time series of daily max/min temperature and precipitation used to calibrate the parameters of VAR model
- VAR model, coupled with monthly mean weather variables (i.e., station mean, climate mean and/or climate projection means), can be used to generate stochastic daily scenarios
- Transform precipitation and temperature time series into Gaussian-distributed random variables through deseasonalization and Principal Component Analysis
- VAR models are calibrated on transformed time series
- Inversely re-transformed into precipitation and/or temperature series
- Account for seasonally changing weather variables, monthly or season time frame

RMAWGEN Output Examples

- VAR model account for seasonally weather variables of precipitation, maximum temperature, and minimum temperature

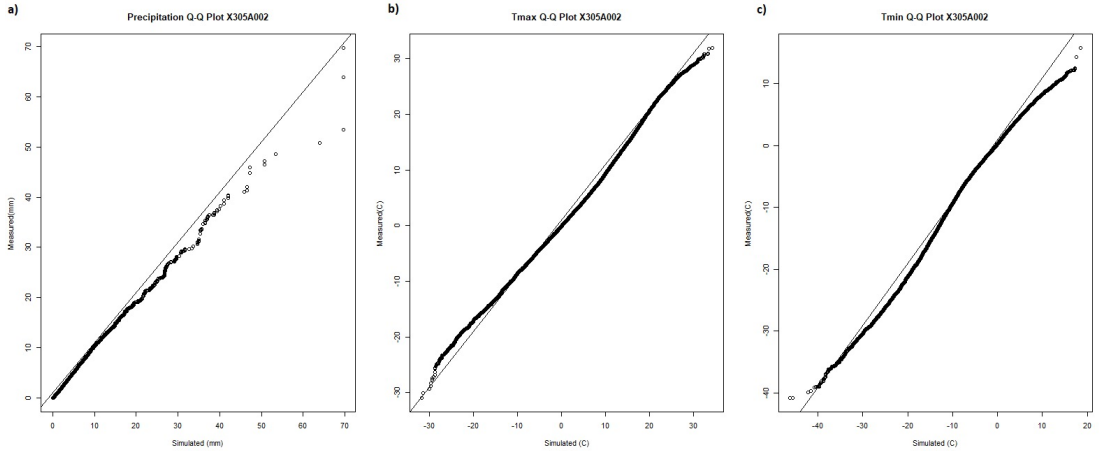


Precipitation and Temperature Calibration

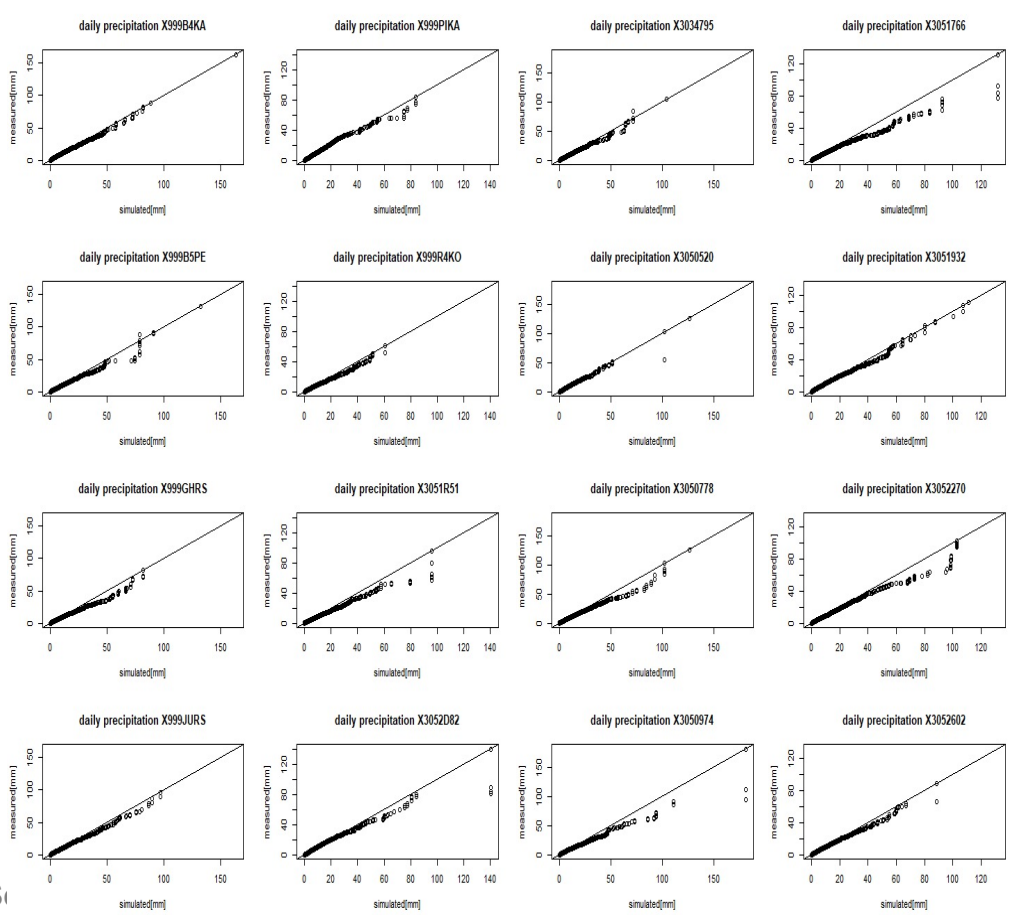
- 35 locations selected to calibrate the RMAWGEN model
- Daily precipitation generated for the reference period 1961-2019 through a random generation with an auto-regression based on generalized linear models
- Calibrated precipitation and temperature models simulated ten 1000-years of daily precipitation, maximum temperature, and minimum temperature
- Based on Wilks' approach for spatial (inter-station) correlations
- VAR precipitation model used exogenous parameter to aid in the prediction of stochastically estimated temperature data

Precipitation and Temperature Simulation

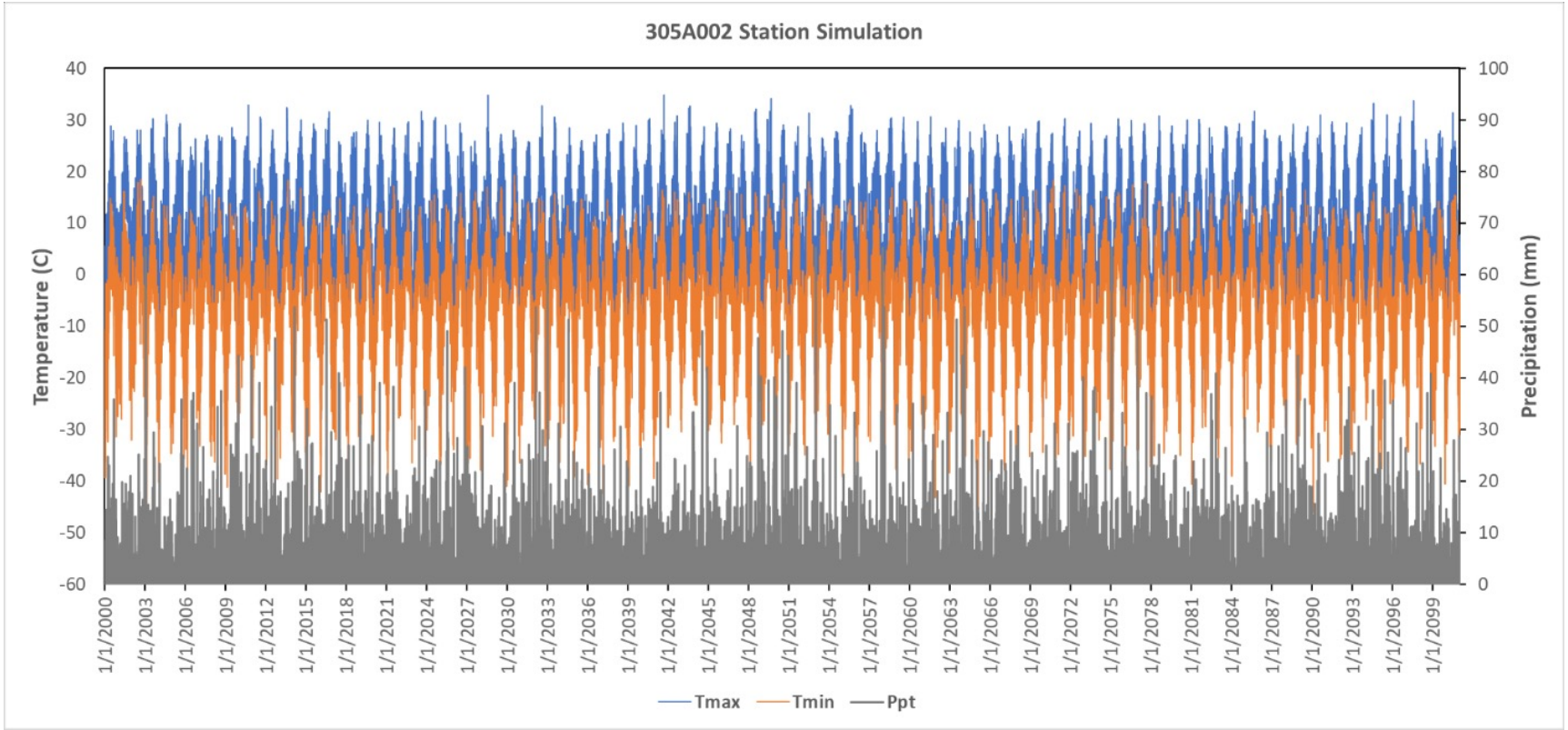
- Calibrated VAR precipitation, maximum temperature, minimum temperature models compared to the observed and simulated data
- Observed vs simulated data were compared at quantiles from 0.1 to 0.99
- Average correlation among the observed and simulated values were excellent with all station's correlation being greater than 0.98



Precipitation and Temperature Simulation



Precipitation and Temperature Simulation



Transposed Synthetic Storms

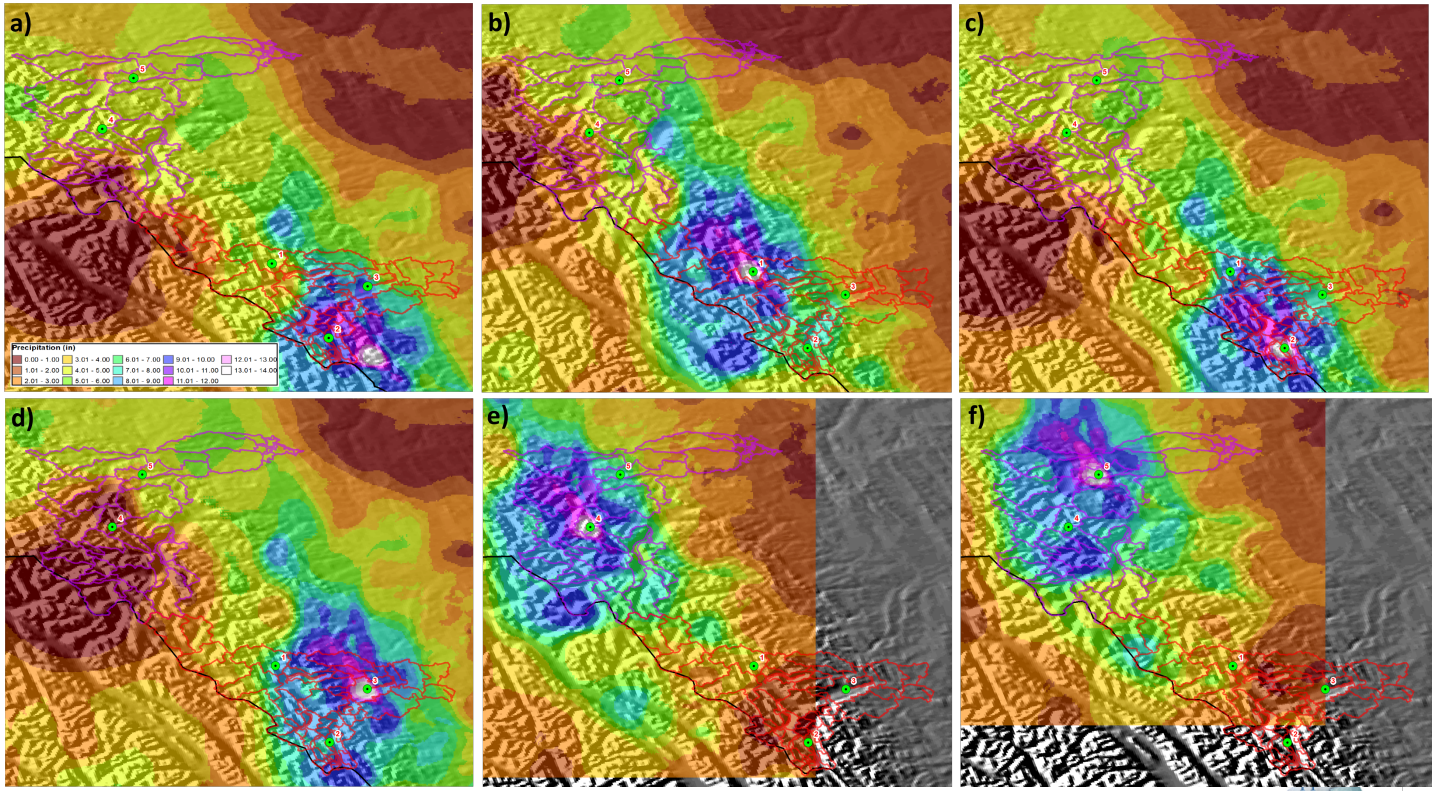
- Account for extreme precipitation events beyond the observed historical dataset
- Apply SHADEX Method
  - Transposed storm pattern and precipitation to five locations within the basin
- Transposed storm locations 1-day precipitation data were extracted at the stations
  - June 2013 station extracted precipitation had upper exceedance probabilities between 10^{-4} and 10^{-6}
- Simulated 3-day rainfall events were inserted in the continuous historical record
  - 3-day events were created based on the transposed precipitation events
  - Scaled to account for the first and last day precipitation
- Scaling factors were based on the average of the June 2013 1-day, 2-day, and 3-day point Depth-Area-Duration (DAD) ratios

Transposed Synthetic Storms

June 2013 (SPAS 1320) total precipitation pattern

~ 350 mm (13.76”) in 72hrs

323 mm (12.7”) @ 2590 km^2 (100 mi^2)



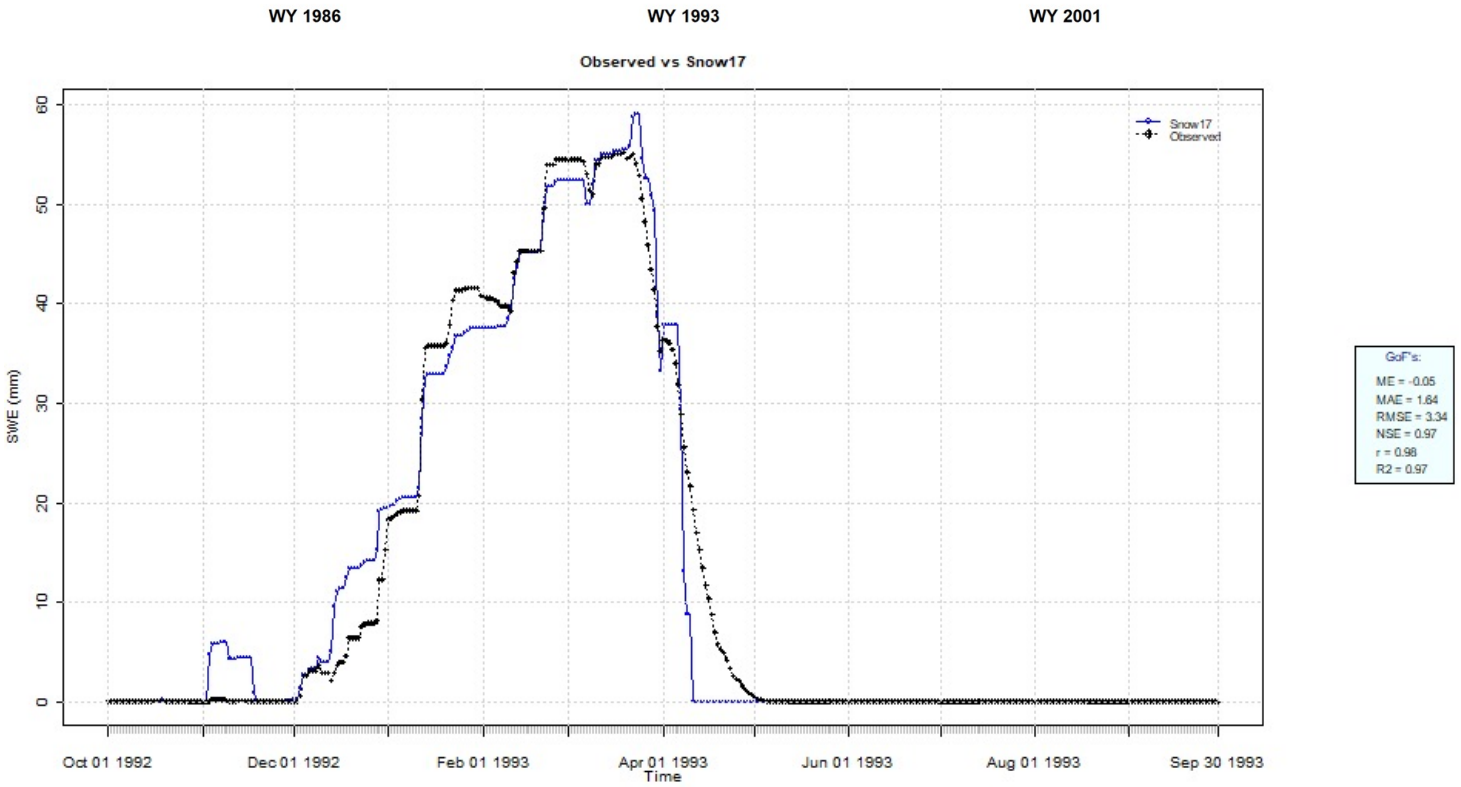
Hydrologic Modelling

- Stochastic data used as the forcing input to a series of calibrated precipitation-runoff models representing the drainage basins for each major reservoir
- Models were built using the Raven framework and UBC Watershed Model emulation
  - Model calibrated against long-duration, multi-year hydrometric records at each reservoir and intermediate Water Survey of Canada (WSC) gauging station, snow pillows when possible
- Hydrologic model was run for 20 simulations of 1,000 years
- Results were used to assess probabilistic flood risk at the 13 dams
  - Considered a wide range of event parameters such as winter snow accumulation, spring melt patterns, glacier melt, summer storm events and operational decisions
- Results will be used in future spillway capacity reviews and dam safety assessments

Other Studies

- AWA applied RMAWGEN model for other basins
  - It maintains the temporal and spatial correlations among sites
  - Accounts for seasonally changing weather variables
  - Orographic, coastal, and non-orographic regions
- Include stochastic generation of snow water equivalent (SWE)
- Include stochastic generation of historic period and climate change/projections scenarios based on representative concentration pathways (RCP) 4.5 and 8.5
- Results will be used in
  - Spillway capacity reviews
  - Nuclear site adequacy evaluations
  - Dam safety assessments

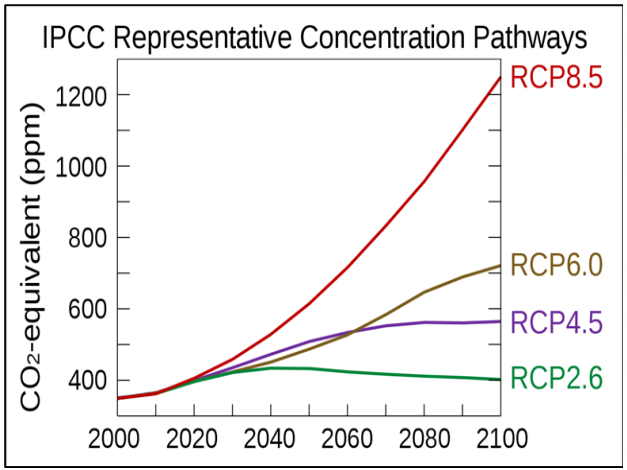
Other Studies: Wet/Dry years, SWE

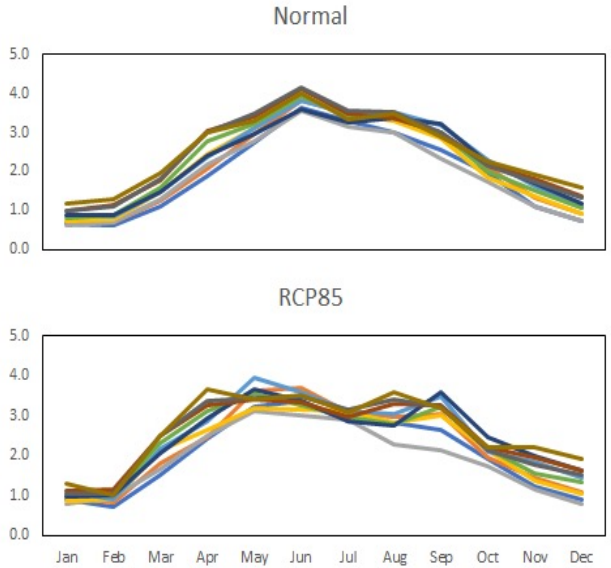


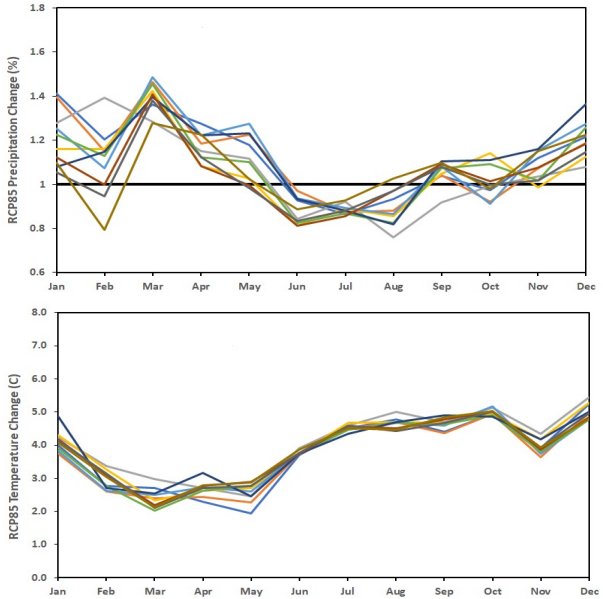
Other Studies: Climate Change

- Projections utilized regional downscaled model output driven by RCP 45 and 85 from CMIP5 global climate model output

- RCP45 and RCP85; represent a mid-level mitigation and no mitigation to limit radiative







Summary

- Simulated daily data for ten 1000-year periods at 35 stations within the Bow basin and the North Saskatchewan basin
  - Calibrated precipitation and temperature VAR models based on daily data from 1961-2019
- RMAWGEN model was selected for the Bow and North Saskatchewan basin because it can maintain the temporal and spatial correlations among the several sites and account for seasonally changing weather variables
- Stochastically simulated daily sequences that provide alternate realizations used for hydrologic assessments throughout both basins
- Hydrologic model results used to assess probabilistic flood risk at the 13 dams
- Results will be used in future spillway capacity reviews and dam safety assessments

THANK YOU

Doug Hultstrand, PhD
Senior Hydrometeorologist
dhultstrand@appliedweatherassociates.com

Bill Kappel
President/Chief Meteorologist
billkappel@appliedweatherassociates.com